PROCEDURE TO DETERMINE SEED LAYER THICKNESS OF TRENCH SIDEWALLS

TECHNICAL FIELD

The present invention generally relates to processing a semiconductor substrate. In particular, the present invention relates to a method of determining whether seed layer thickness on trench sidewalls is sufficient for desired circuit performance.

BACKGROUND ART

In the semiconductor industry, there is a continuing trend toward higher device densities. To achieve these high densities there has been and continues to be efforts toward scaling down the device dimensions on semiconductor wafers (*e.g.*, at submicron levels). In order to accomplish such high device packing density, smaller and smaller features sizes are required. This may include the width and spacing of interconnecting lines, spacing and diameter of contact holes and the surface geometry such as corners and edges of various features.

The requirement of small features with close spacing between adjacent features requires high resolution photolithographic processes. In general, lithography refers to processes for pattern transfer between various media. It is a technique used for integrated circuit fabrication in which a silicon slice, the wafer, is coated uniformly with a radiation-sensitive film, the resist and an exposing source (such as optical light, x-rays, etc.) illuminates selected areas of the surface through an intervening master template, the mask, for a particular pattern. The lithographic coating is generally a radiation-sensitive coating suitable for receiving a projected image of the subject pattern. Once the image is projected, it is indelibly formed in the coating. The projected image may be either a negative or a positive image of the subject pattern. Exposure of the coating through a photomask causes the image area to become either more or less soluble (depending on the coating) in a particular

solvent developer. The more soluble areas are removed in the developing process to leave the pattern image in the coating as less soluble polymer.

The ability to reduce the size of computer chips while increasing packing densities and performance is driven by lithography technology and metallization processes and is especially critical to ultra large scale integration (ULSI) circuits. ULSI circuits require responsive changes in interconnection technology which is considered a very demanding aspect of ULSI technology. High density demands for ULSI integration require planarizing layers with minimal spacing between conductive lines and/or trenches.

Traditional methods of forming interconnection structures include the use of photoresist patterning and chemical or plasma subtractive etching as the primary metal technique. However, because the geometry of semiconductor circuits continues to decrease, traditional interconnection techniques are unsuitable. In particular, problems associated with traditional methods include trapping impurities or volatile materials, such as aluminum chloride, in interwiring spaces (i.e., may pose reliability risk to device), leaving residual metal stringers (i.e., may cause electrical shorts), and poor step coverage. These problems contribute to low yields, poor performance, and lower layout densities. More recent developments in interconnect technology have improved, however, problems such as non-uniform seed layer deposition and void formation within the seed layer still contribute to poor device performance and product yield losses. The seed layer is commonly deposited or formed over a barrier layer for the purpose of providing a material on which a subsequently deposited material will readily form. Therefore, seed layer coverage is critical to the formation and performance of the interconnect structure.

Therefore, there is an unmet need for a process to determine the sufficiency of seed layer coverage in the sidewall portions of a trench.

SUMMARY OF THE INVENTION

The present invention provides a system and a method for monitoring in-situ and controlling seed layer coverage throughout the surfaces of a trench. By

monitoring the thickness of the seed layer during semiconductor processing, one or more process control parameters may be adjusted to help achieve a desired seed layer coverage. As a result, the number of process steps required to achieve the desired seed layer coverage may be reduced, providing a more efficient and economical process.

One aspect of the present invention provides a semiconductor processing system. The system includes a processing chamber operable to form a seed layer over a barrier layer conformal to a trench surface, particularly the trench sidewalls, in the chamber. The barrier layer is formed over another layer which includes a trench therein. An x-ray scattering/reflectometry system performs in-situ thickness measurements of the seed layer being formed and provides a measurement signal indicative of the measured thickness. In accordance with another aspect of the present invention, the thickness of the seed layer may also be monitored and controlled. A signature is then generated utilizing the measurement signal and the signature is compared with a library of signatures to determine the thickness of the seed layer.

To the accomplishment of the foregoing and related ends, certain illustrative aspects of the invention are described herein in connection with the following description and the annexed drawings. These aspects are indicative, however, of but a few of the various ways in which the principles of the invention may be employed and the present invention is intended to include all such aspects and their equivalents. Other advantages and novel features of the invention will become apparent from the following detailed description of the invention when considered in conjunction with the drawings.

BRIEF DESCRIPTION OF DRAWINGS

Figure 1 illustrates a high-level block representation of a system in accordance with one aspect of the present invention.

Figure 2 illustrates a high-level block diagram illustrating an example of a measurement system employing x-ray reflectometry that may be utilized in accordance with one aspect of the present invention.

Figure 3 illustrates a high-level block diagram illustrating an example of a measurement system employing x-ray reflectometry in accordance with one aspect of the present invention.

Figure 4 illustrates a block diagram of program modules that reside in a memory system in accordance with one aspect of the present invention.

Figure 5 illustrates a graph of exemplary x-ray reflectometry data corresponding to the thickness of a seed layer in accordance with one aspect of the present invention.

Figure 6 illustrates a flow diagram illustrating a methodology for measuring a thickness of a seed layer in accordance with one aspect of the present invention.

DISCLOSURE OF INVENTION

The present invention involves a system and a method for monitoring in-situ and controlling seed layer coverage throughout the surfaces of a trench. One aspect of the present invention generally relates to using x-ray reflectometry to determine the sufficiency of seed layer coverage at the sidewall portions of a trench. In particular, x-ray reflectometry may be employed to determine the thickness of the seed layer during or after it has formed on the side and bottom surfaces of the trench. Alternatively or in addition, a profile of the seed layer may be measured to determine sufficiency of sidewall coverage. The system and method mitigate void formation associated with insufficient seed layer deposition within and over the surfaces of a trench (via) related to forming interconnect structures, capacitors, and the like.

The system and method employ a library of signatures which are stored in a memory. An x-ray beam is directed to the surface of a seed layer, and the reflected beam is collected and analyzed. One or more signatures of the reflected x-ray beam can be generated and the one or more signatures are compared to the signatures of the library, so as to determine the approximate thickness of the seed layer. The thickness of the seed layer can be monitored and determined during or after its formation. The system and method can be employed in-situ, so that the thickness of the seed layer can be monitored and controlled during fabrication of the device/feature. As a result, seed

layer formation may be optimized thereby mitigating product yield losses and ineffective performance of the device.

The present invention is to be described with reference to Figures 1-6 below, wherein like reference numerals are used to refer to like elements throughout. In the following description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It may be evident, however, to one skilled in the art that the present invention may be practiced without these specific details. In other instances, well-known structures and devices are shown in block diagram form in order to facilitate description of the present invention.

Referring initially to Figure 1, a system 10 for monitoring in-situ a seed layer deposition process 12 throughout the sidewall portions of a trench is shown. The system 10 may also facilitate measuring the thickness of the seed layer at the sidewall portions to determine substantial coverage. The process 12, for example, includes deposition of a seed layer (*e.g.,* copper and copper alloys including copper-zinc, copper-aluminum, copper-zinc-aluminum, copper-nickel, copper-silver, copper-gold, copper-platinum and copper-paladium, or a combination thereof) over a barrier layer (*e.g.,* metallic nitride or metal), both of which are formed over a layer or substrate having at least one trench formed therein. The barrier layer and seed layer are conformal to the trench surfaces (*i.e.,* side and bottom surfaces).

The system 10 also includes a control system 14 for controlling operating characteristics of the process 12. The operating characteristics associated with the process 12 may include, for example, deposition enablement, temperature, concentration of gases within the process, pressure associated with the process, and timing parameters associated with different steps in a multi-step fabrication process. The control system 14 may adjust one or more selected operating parameters of the process 12 based on sensed operating conditions associated with such process 12.

A measurement system 16 is operatively associated with the process 12 to measure in-situ thickness of the seed layer as it is being formed. That is, the measurement system 16 includes a thickness monitoring portion 18, which may be

located within or integrated into the process 12. The thickness monitoring portion 18 may also include an enclosed processing chamber. The measurement system 16, for example, samples the thickness of layers being formed on the substrate at one or more locations, such as near the center and near one or more edge locations of the substrate. In particular, it may be desirable to obtain measurements from two or more spaced-apart locations, such as the center and one or more edge positions. Such measurements may enable a better determination as to uniformity of the layer thickness, which in accordance with an aspect of the present invention, may be employed to adjust the fabrication process to achieve a desired level of uniformity of layer thickness.

The measurement system 16 may implement any known technique operable to measure the thickness of the layer formed in the process 12. Examples of techniques that may be utilized in accordance with an aspect of the present invention include optical interference, x-ray reflectometry, capacitance and use of an associated color chart. Microprocessor-controlled optical interference (*e.g.*, microspectrophotometry) is a common type of optical measurement techniques that could be employed.

The measurement system 16 is coupled to the control system 14 for providing a signal indicative of the measured layer thickness being formed in the process 12. The control system 14, for example, includes a memory (not shown) for storing a target layer thickness, which may vary according to the process. The control system 14 also includes a signature generation system 16, which creates a signature from or based on the signal measurements over a pre-determined spectral range. The control system 14 also includes a signature library 22 that includes hundreds of thousands of signatures, each corresponding to a particular type and thickness of seed layers. The signatures may also correspond to profiles of trenches having desired seed layer coverage particularly at the sidewall portions.

An analysis system 20 is provided for comparing the generated signature with signatures in the signature library 22. By examining a signature library 22 of reflectivity intensity/scattering angle signatures, a determination can be made concerning the properties of the surface, such as thickness of the layer being formed

thereon. The control system 14 is coupled to the process 12 and maybe programmed and/or configured to compare the measured thickness relative to the target thickness and determine what action, if any, should be taken to drive the process 12 so that a target thickness and/or a desired level of uniformity of thickness may be achieved. The control system 14 is also coupled to an output device 24 which may be used to display results to a user.

The system 10 further may include one or more process sensors (not shown) for monitoring process operating conditions and providing an indication of such conditions to the control system 14. Thus, the control system 14 is able to adjust process operating conditions based on the measured thickness (*e.g.*, based on a generated signature from the measurement system 16) and the sensed process operating conditions (*e.g.*, based on a signal from the other process sensors). In this way, the control system 14 may selectively refine the seed layer formation process 12 to accommodate variations in sensed process conditions and measured layer thickness at various stages of the layer formation process. For example, the control system 14 may adjust gas flow rates, pressure, temperature, and/or layer formation time (*e.g.*, deposition time or layer growth time) based on the conditions monitored by the measurement system 16 and the one or more sensors. As a result, the system 10 is capable of achieving substantially uniform seed layer coverage at the sidewall portions of the trench without substantial void formation and without an increase in process steps to refine the process.

According to one aspect of the invention, x-ray reflectometry is employed to monitor and control the seed layer thickness. X-ray reflectometry is a non-destructive optical technique, which deals with the measurement and interpretation state of x-rays scattering from a sample surface boundary. When x-rays strike a surface at glancing incidence, they can reflect (or scatter) from the surface. However, if the surface is rough or covered by a film, then the x-ray reflectivity of a surface can change. X-ray reflectometry takes advantage of this effect by measuring the intensity of x-rays reflected from a surface as a function of an angle (referred to as an incident or scattering angle). Total reflection occurs for incident angles smaller than the critical

angle. The critical angle of total reflection is small (*e.g.*, ~0.2°-1° for a wavelength λ of ~0.1 nm) and interferences from thin films are only visible in a small range about the critical angle. Reflectometry is sensitive only to electron density and absorption and does not depend on crystallinity and crystal texture. Reflected intensity (R_F) is given by known Fresnel equations. The reflected intensity may be calculated using a recurrence formalism which calculates the reflection coefficient starting from the lowest surface boundary (*e.g.*, substrate) up to the last surface boundary (*e.g.*, surface/air). With a recurrence code (*e.g.*, REFSIM by Siemens or REFS by Bede Scientific) a simulation of x-ray reflectometry spectra can be done. The parameters film thickness, density and roughness may be extracted from the interference spectra, the critical angle and the decrease of the reflectivity as schematically shown in Figure 5. For example, thin films on a surface may give rise to oscillations of the x-ray intensity as a function of the incident angle.

In addition, the characteristic scattering of x-rays from atoms may also be done in lattices, referred to as Bragg scattering and exemplified by the formula $n\lambda = 2d \sin \theta$, where n is an integer, λ is the x-ray wavelength, d is the spacing between layers (analogous to layer thickness or depth), and θ is often referred to as the Bragg or incident angle. Bragg scattering gives information about type and changes in a crystal lattice. Scattering x-ray radiation from thin films is somewhat analogous to scattering radiation at plane parallel plates. However, in the latter case, special care must be taken since the refractive index for all materials is close to 1, and total reflection occurs for incident angles smaller than the critical angle. Total reflection may also occur because when dealing with x-rays, it is important to note that any material is optically thinner than air. Oscillations of x-ray intensity are only visible in a small range around the critical angle θ_c (see Figure 5).

Figure 2 illustrates an example of an x-ray reflectometry system 40 that may be implemented in accordance with the present invention to measure the thickness of a seed layer 51 (including sidewall portions 52) as it is formed on a barrier layer 54 over a substrate 56. The x-ray reflectometry system 40 includes a measurement system 42 coupled to a light source 44 and a detector 46. The light source 44 may be

an x-ray tube of polychromatic x-ray radiation. Light beam 48 from the light source 44 travels through a collimator 60 and a crystal monochromator 62, which is located between the light source 44 and a sample holder (not shown). To switch the measurement to a new spectral region, it is necessary to rotate the monochromator 62 as well as other elements of this system 40 corresponding to a new Bragg angle.

At least a portion of the x-ray beam is reflected, indicated at 50, and received at the detector 46. The detector 46 measures the intensity of the scattered x-rays through the desired range of incident angles that pass through an analyzer 66. The analyzer 66 serves to maintain the reflected beams 50 incident upon it with their corresponding spectral region so that the detector 46 can characterize them. The detector 46 or the measurement system 42 may then determine x-ray reflectivity as a function of an incident angle, referred to as θ. One or more signatures are thus generated corresponding to the scattering angle and x-ray reflectivity. Hence the generated signature corresponds to the thickness of the seed layer sidewall portions 52 of the seed layer 51.

According to another aspect of the invention, surface roughness σ_{rms} of sidewall portions of a seed layer may be determined using x-ray reflectometry. However, measuring roughness differs slightly from measuring thickness. Surface roughness may be calculated by the formula: $R_F^{rough} = R_F \exp(-K_z^2 \sigma_{rms}^2)$, where R_F is the reflected intensity and $|K_z| = 2\pi \sin\theta/\lambda$. The system 10 (Figure 1), together with the x-ray reflectometry system 40 (Figure 2) may be employed as described above to determine surface roughness. However, to obtain vertical surface and interface roughness measurements, the x-ray scattering vector (incident angle) must be perpendicular to the surface. On an x-ray reflectivity spectrum, such as shown in Figure 5 below, surface roughness may be indicated by a drop in reflectivity (intensity).

Figures 3-4 illustrate examples of a system for employing x-ray reflectometry techniques to determine the thickness of seed layer formed on trench sidewalls. Figure 3 illustrates a system 100 having an x-ray scattering system 102 for in-situ layer thickness monitoring in accordance with one aspect of the present invention. In

this example, the system 100 forms a seed layer 138, such as copper, by chemical vapor deposition (CVD). The seed layer 138 is formed over a barrier layer 136 disposed over a substrate 134. The barrier 136 and seed 138 layers are conformal to the trench 139 as well as to the substrate surface. The barrier layer 136 may be tantalum nitride or any other metallic nitride film. Examples of CVD processes that may be utilized, in accordance with an aspect of the present invention, include Low Pressure CVD (LPCVD), Plasma Vapor Deposition (PVD), and Electrochemical deposition (ECD) such as electroplating. It is to be appreciated, however, that the present invention is applicable to other types of thin film formation, such as other deposition techniques and film growth techniques.

The system 100 includes a process chamber 122 that includes a support, such as a stage 132 (or chuck) operative to support the substrate 134, such as a wafer. A positioning system 126 is operatively connected to the support 132 for positioning the stage 132 at a desired position within the chamber 122. It is to be appreciated that wafer positioning systems are rapidly evolving and that any such system may be employed in accordance with an aspect of the present invention.

A seed layer gas distribution system 114 is operably coupled to the chamber 122 for selectively providing gaseous chemicals into the chamber 122 to form the seed layer layer 138 on the substrate 134. By way of illustration, the gas distribution system 114 includes a source of a gaseous medium (a vapor) of seed layer material (*e.g.*, copper) to be formed on the substrate. The gas is provided into the chamber through a conduit that terminates in a nozzle, indicated at 120. While, for purposes of brevity, a single nozzle 120 is shown in Figure 3, it is to be appreciated that more than one nozzle or other gas delivery mechanisms may be utilized to provide gas into the chamber 122 for film formation in accordance with an aspect of the present invention.

The system 100 also may include a load system 124 operatively connected to the chamber 122 for loading and unloading substrates (*e.g.*, wafers) into and out of the processing chamber 122. The load system 124 typically is automated to load and unload the wafers into the chamber 122 at a controlled rate. The x-ray scattering system 102, which communicates with the chamber 122, is operative to measure film

thickness in-situ, in accordance with an aspect of the present invention. In the example illustrated in Figure 3, the x-ray scattering system 102 is operative to measure the thickness of the seed layer 138 in addition to the thickness of the sidewall portions 140 of the seed layer 138.

The x-ray scattering system 102 includes a polychromatic light source 128, a collimator 125, a monochromator 127, an analyzer 131 and a detector 130. Alternatively, the x-ray scattering system 102 may have a cutting slit, a Göbel mirror, an antiscatter slit and a detector slit (all not shown). The x-ray scattering system 102 operates in the same manner as the x-ray reflectometry system 40 described in Figure 2. The polychromatic light source 128 provides a light beam 142 toward an exposed surface of the barrier layer 136 on which the seed layer 138 and sidewall portions 140 of the seed layer 138 are being formed. Alternatively or in addition, the light beam 142 may be directed at the sidewall portions of the seed layer during and after the seed layer 138, 140 has formed on the surface of the barrier layer 136.

The beam 142 interacts with the surface and layer(s) and is reflected. The reflected beam(s) 144, which is received at the detector portion of the source/detector 130, has beam properties (*e.g.,* intensity and/or phase), which may be employed to determine an indication of layer thickness. A plurality of incident beams from one or more sources also may be directed at different spaced apart locations of the barrier layer 136 to obtain corresponding measurements of layer thickness substantially concurrently during the fabrication process. The concurrent measurements, in turn, provide an indication of the uniformity of layer thickness across the substrate. By way of illustration, the intensity of light over a selected wavelength and range of incident angles varies as a function of layer thickness in x-ray reflectometry.

The x-ray scattering system 102 provides information indicative of the measured properties to a control system 106. Such information may be the raw phase and intensity information. Alternatively or additionally, the x-ray scattering system 102 may be designed to derive an indication of layer thickness based on the measured optical properties and provide the control system 106 with a signal indicative of the measured layer thickness according to the detected optical properties. The scattering

(incident) angle and intensity of the reflected light can be measured and plotted in a spectrum.

In order to determine layer thickness, for example, measured signal characteristics may be employed to generate a signature corresponding to the reflectivity intensity over the angle range. The generated signatures may be compared with a signal (signature) library of known signatures of the same to determine the thickness of the seed layer 138 and/or the thickness of the sidewall portions 140 of the seed layer 138. Such substantially unique x-ray reflectivity intensity signatures are produced by light reflected from and/or refracted by different surfaces due, at least in part, to the complex index of refraction of the surface onto which the light is directed.

The signature library can be constructed from observed intensity/angle signatures and/or signatures generated by modeling and simulation. By way of illustration, when exposed to a first incident light of known intensity, wavelength and angle, a first feature on a wafer can generate a first component of an intensity/angle signature. Similarly, when exposed to the first incident light of known intensity, wavelength and angle, a second feature on a wafer can generate a second component of a intensity/angle signature. The components can be determined over a pre-determined range of incident angles and aggregated to form a signature. For example, a particular type of thin film having a first thickness may generate a first signature while the same type of film having a different thickness may generate a second signature, which is different from the first signature.

Observed signatures can be combined with simulated and modeled signatures to form the signature library. Simulation and modeling can be employed to produce signatures against which measured intensity/angle signatures can be matched. In one exemplary aspect of the present invention, simulation, modeling and observed signatures are stored in a signature library containing, for example, over three hundred thousand intensity/angle signatures. Thus, when the intensity/angle signals are received from x-ray scattering detecting components, the intensity/angle signals can be pattern matched, for example, to the library of signatures to determine whether the signals correspond to a stored signature. Interpolation between the two closest

matching signatures may be employed to discern a more accurate indication of thickness from the signatures in the signature library. Alternatively, artificial intelligence techniques may be employed to calculate desired parameters of the wafer under test based on the detected optical properties.

The control system 106 includes a processor 110, such as a microprocessor or CPU, coupled to a memory 108. The processor 110 receives measured data from the x-ray scattering system 102. The processor 110 also is operatively coupled to the seed layer material gas distribution system 114, the positioning system 126 and the load system 124. The control system 106 is programmed/and or configured to control and operate the various components within the processing system 100 in order to carry out the various functions described herein. The processor 110 may be any of a plurality of processors, such as the AMD K6®, ATHLON™ or other similar processors. The manner in which the processor 110 can be programmed to carry out the functions relating to the present invention will be readily apparent to those having ordinary skill in the art based on the description provided herein.

The memory 108 serves to store program code executed by the processor 110 for carrying out operating functions of the system as described herein. The memory 108 may include read only memory (ROM) and random access memory (RAM). The ROM contains among other code the Basic Input-Output System (BIOS) which controls the basic hardware operations of the system 100. The RAM is the main memory into which the operating system and application programs are loaded. The memory 108 also serves as a storage medium for temporarily storing information such as temperature, temperature tables, position coordinate tables, interferometry information, thickness tables, and algorithms that may be employed in carrying out the present invention. The memory 108 also can hold patterns against which observed data can be compared as well as information concerning grating sizes, grating shapes, x-ray reflectivity/scattering information, achieved profiles, desired profiles and other data that may be employed in carrying out the present invention. For mass data storage, the memory 108 may include a hard disk drive.

A power supply 116 provides operating power to the system 100. Any suitable power supply (*e.g.*, battery, line power) may be employed to carry out the present invention. The system further may include a display 104 operatively coupled to the control system 106 for displaying a representation (*e.g.*, graphical and/or text) of one or more process conditions, such as layer thickness, temperature, gas flow rates, etc. The display 104 further may show a graphical and/or textual representation of the measured optical properties (*e.g.*, refraction index, critical angle, and absorption constant) at various locations along the surface of the substrate.

As a result, the system 100 provides for monitoring process conditions, including layer thickness and other sensed process-related conditions, associated with the layer formation process within the chamber 122. The monitored conditions provide data based on which the control system 106 may implement feedback process control in a closed loop so as to form a seed layer 138 having a desired uniform thickness in the sidewall portions 140 of the trench 139 so as to obtain sufficient coverage of the trench sidewalls.

Figure 4 illustrates a plurality of program modules that can reside in a memory 210 employed in the systems illustrated in Figure 3. The memory 210 includes a system control module 220 for controlling the initialization of components in the system, the load system, the positioning system and rotation of the chuck. The system control module 220 also operates as a kernel for providing a central communication mechanism between the other modules in the memory 210. A deposition control module 230 provides control for enabling and disabling the seed material gas distribution system. The measurement control module 240 initializes and controls the x-ray reflectometry system for operating the polychromatic light source, rotation of the monochromator or analyzer and sampling of the detector. A signature generation module 250 aggregates the raw signal samples from the x-ray reflectometry system and provides an actual measured signature of the thickness of the sidewall portions 140 of the seed layer 138 (Figure 3). The signature analysis module 260 searches a signature library 270 and compares the actual measured signature(s) with stored signatures in the signature library 270.

Once a match of the signatures is determined, a corresponding thickness is determined and passed back to the system control module 220. The system control module 220 then determines if the optimal thickness has been achieved. If the optimal thickness has been achieved, the system control module 220 notifies the deposition control module 230 to terminate deposition of the material or oxidation of the material.

Turning now to Figure 5, an exemplary spectrum 300 showing data 310 characteristic of the x-ray reflectometry system 102 is illustrated. The data 310 corresponds to a multi-layer structure such as, for example, a seed layer over a barrier layer which is formed conformal to a trench and over a substrate. The spectrum 300 represents reflectivity 320 (x-ray intensity) as a function of an incident angle 330. The data 310 associated with the spectrum 300 is with respect to the critical angle 340 having a 0.5 reflectivity and the wavelength λ being about 0.10 nm.

Interference patterns 360 from thin films are only visible in a small range about the critical angle. Thus, as shown in the spectrum 300, the interference pattern 360 is observed in a small range from the critical angle 340. According to x-ray reflectometry theory, the film thickness 350 for a thin layer such as a barrier layer (over a substrate) can be determined by the formula: $d \cong \lambda/(2\Delta\theta)$, where d is the layer thickness, λ is the x-ray wavelength, and $\Delta\theta$ is the change in angle. A thin film layer (on a substrate) will produce oscillations 350 in the reflectivity related to the layer's thickness known as Kiessig fringes 350. As can be seen by the spectrum 300 at oscillations 350, there is little or no change in the angle θ (at dashed arrows). Therefore, according to the formula, the thickness d will be relatively larger than for the layer represented by 360. In addition, rapid oscillations correspond to a relatively thick layer and wider oscillations correspond to a thinner layer. Thus, the relatively rapid oscillations 350 in the spectrum 300 support the above conclusion.

An interference pattern (beat) is created when more than one layer is present, as schematically indicated by 360. That is, the interference pattern represents the thickness of a layer formed over another layer on a substrate. Here, the interference pattern 360 indicates the thickness of a second layer such as a seed layer, particularly

sidewall portions of a seed layer. As can be seen by the interference pattern or beat 360, the change in angle $\Delta\theta$ is greater than at the oscillations 350. This means that the sidewall portions of the seed layer are thinner than the barrier layer. More importantly, actual thickness measurements for the sidewall portions of the seed layer may be ascertained by using the formula $d \cong \lambda/(2\Delta\theta)$ as stated above. Thus, sufficient coverage of the seed layer over the sidewall portions of the trench can be determined by calculating the thickness of the seed layer formed on the sidewalls.

In addition to information provided by the oscillations 350 and interference pattern 360, a drop in intensity (reflectivity), indicated at 370 and by the angle range 372, illustrates an amount of surface roughness. Information related to the surface roughness of a layer may indicate planarization requirements and/or deficiencies. Surface roughness of the seed layer on the sidewall portions of the trench may or may not adversely affect performance of the subsequently fabricated device. However, roughness may be determined in order mitigate device error.

In view of the exemplary systems shown and described above, a methodology, which may be implemented in accordance with the present invention, will be better appreciated with reference to the flow diagram of Figures 6. While, for purposes of simplicity of explanation, the methodology of Figures 6 is shown and described as executing serially, it is to be understood and appreciated that the present invention is not limited by the illustrated order, as some blocks may, in accordance with the present invention, occur in different orders and/or concurrently with other blocks from that shown and described herein. Moreover, not all illustrated blocks may be required to implement a methodology in accordance with the present invention.

Turning now to Fig. 6, the methodology begins at 400 in which a substrate is positioned within an appropriate environment for desired processing. In this example, the processing is to include formation of a barrier layer over a multi-layer structure, such as, for example, a tantalum nitride layer formed conformal to a trench formed in a polysilicon layer over an oxide layer over a silicon substrate. After the substrate is positioned, the process proceeds to 410 in which a multi-layer structure is formed on the substrate. At 420, deposition of the seed layer over the multi-layer structure

begins. As mentioned above, seed layer film formation may occur on a barrier layer, such as a metallic nitride film, through a known deposition or film growth technique such that the seed layer is conformal to the trench. The process then proceeds to 430. At 430, the thickness of the thin layer being formed is measured. By way of example, the layer thickness is measured in-situ by an x-ray reflectometry system, although other non-destructive thickness measuring techniques also could be utilized in accordance with the present invention. Alternatively or in addition, a profile of the seed layer formed over the barrier layer, including the sidewall portions may be measured.

From 430, the process proceeds to 440 in which a determination is made as to whether the measured thickness of the sidewall portions of the seed layer are within expected operating parameters. This determination, for example, may include a comparison of the measured thickness with an expected (or target) value, such as may be derived based on previous processes, calculations using monitored operating conditions within the processing chambers, and/or a combination thereof. For example, a signal signature indicative of reflected and/or refracted light may be compared relative to a signature library to provide an indication of the thickness based on its intensity of the reflected and/or refracted light. If the thickness is within expected operating parameters, the process proceeds to 450. At 450, the process terminates the deposition of the seed layer material. If the thickness is not within expected operating parameters, the process returns to 420 and continues the deposition process. Alternatively or in addition, the above processes may also be performed using a measured profile; in particular, a comparison between a measured profile and a profile signature as described above.

Although the invention has been shown and described with respect to a certain preferred embodiment or embodiments, it is obvious that equivalent alterations and modifications will occur to others skilled in the art upon the reading and understanding of this specification and the annexed drawings. In particular regard to the various functions performed by the above described components (assemblies, devices, circuits, etc.), the terms (including any reference to a "means") used to

describe such components are intended to correspond, unless otherwise indicated, to any component which performs the specified function of the described component (i.e., that is functionally equivalent), even though not structurally equivalent to the disclosed structure which performs the function in the herein illustrated exemplary embodiments of the invention. In addition, while a particular feature of the invention may have been disclosed with respect to only one of several embodiments, such feature may be combined with one or more other features of the other embodiments as may be desired and advantageous for any given or particular application.